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VOLUME V

Final Report

TECHNICAL DOCUMENTARY REPORT NO. ESD-TDR-64-234

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ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

ESRH

Project 7682, Task 768204

AD616545

(Prepared under Contract No. AF 19 (628)-455 by Bio-Dynamics Incorporated, Cambridge, Massachusetts.)

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FOREWORD

One of the research goals of the Decision Sciences Laboratory is the development of design principles for automated training subsystems which could be built into future Information Systems. Such subsystems would provide Information Systems with the capability of training automatically their own operators. To be able to design such a capability requires first the solution of many conceptual and experimental problems. This final report summarizes design principles, equipment and experiments produced under Contract AF 19(628)-455.

This report is one in a series supporting Task 768204, Automated Training for Information Systems, under Project 7682, Man-Computer Information Processing. The research was conducted from 1962 to 1964. The Principal Investigator was Dr. Thomas B. Sheridan, and the Contract Monitor was Dr. Sylvia R. Mayer.

A number of members of Bio-Dynamics' staff have contributed directly to the accomplishment of various portions of this study. These include T. J. Cummings, B. C. Duggar, A. R. Johnson, J. Mickunas, A. W. Mills, and R. Rosenberg.

PUBLICATION REVIEW AND APPROVAL

This Technical Documentary Report has been reviewed and is approved.

FOR THE COMMANDER

DONALD W. CONNOLLY
Chief, Display Division
Decision Sciences Laboratory

ROY MORGAN
Colonel, USAF
Director, Decision Sciences Laboratory

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I. INTRODUCTION

The training of operators for computer-based systems is an expensive undertaking. Because of the rapid pace of system evolution, operator training is a continuing requirement. Furthermore, the number of individuals receiving an identical instruction program at any one time is often extremely small. The resultant high instruction/student ratio requirements escalate training costs and complicate planning. The need and the potential value of automated training for improving this situation has been demonstrated (1, 2, 3, 4, 5, 6).

Air Force research and development in automated training has progressed to the point where refinement of design principles and specifications for implementation are appropriate research objectives. In some instances, "teaching machines" will be, or are being, used to acquire skills, and simulators are being used to exercise these acquired skills. However, present and future Air Force Information Systems perform functions and have capabilities which overlap the requirements of automated instructional systems and simulators. Since the subject matter to be taught the operators of information systems is intimately related to the specific equipment for the particular task, there are many advantages of involving in the training program the very same equipment which eventually will be used on the job. Because of this overlap of operational and instructional requirements, inclusion within the operational equipment of subsystems which perform this instructional function appears both desirable and feasible.

This report describes the results and conclusions of a study initiated in July 1962 and completed in December 1964 which was directed at the development of principles for the design of automated instruction subsystems for Information Systems. A series of four Technical Documentary Reports have been issued which describe in detail the activities and results of each aspect of the study (7, 8, 9, 10). This report brings together and summarizes the results reported in the individual documents, and includes additional items which did not warrant separate documentation.

II. APPROACH

A variety of tasks were selected for experimental evaluation of instructional concepts and requirements. The three tasks used in the major experiments were characterized by three widely differing skills:

1. Control sequencing--in one type of experiment, the operator had to perform a particular sequence of actions depending upon the display conditions (the functions of the controls and how they were used were not important).

2. Problem analysis and selection of required control functions--in this type of experiment, the subject was to acquire an understanding of the functions of each of a number of available controls and how they interact.

3. Querying and reasoning--in this experiment, based on the information gained from answers to successive queries, the operator had to develop or refine hypotheses and select additional queries with which to test them.

Alternative training programs were developed for each of the tasks and experiments designed to evaluate them. The training methods were

selected to evaluate several dimensions of instructional techniques:

1. Structuring of the training experience--ranging from operant conditioning to formal lecture/demonstration presentations.

2. Program order--the "discovery" principle of ordering programs.

3. Display techniques--taped lectures and slides versus instruction manuals.

4. Language--words versus graphical logic flow diagrams.

It was then possible to develop some general design principles for providing the required system capabilities. Since computers have already been shown to have great potential for controlling instruction programs (11, 12), the major emphasis of this study was on exploitation of the overlap of external features of operational equipment with those features required to teach the task.

III. RESULTS

A. Experiments

The first task in the research program was to develop a graphical-symbolic description of an exemplary Air Force Information System operator's task. The SAGE Intercept Director's job was chosen for this purpose, partly because the potential value of automated instructional techniques had already been demonstrated in this context. An abstract hardware model was subsequently developed, training programs devised, and automated instruction carried out using the hardware model and graphical symbology. It was determined that when the control sequences were

outlined in the form of a graphical logic flow diagram drawn on the console, individuals who understood the symbology required no task instruction (7). The graphical symbology was found to provide a concise language which is an efficient medium for teaching the task logic, and the diagrams were capable of being used as self-teaching programs. Additional experiments demonstrated that the task could be taught without symbology pre-instruction provided that response evaluation and immediate reinforcement was given to the trainee (7). However, it should be noted that console layout must correspond topologically to the task logic flow diagrams if this technique is to be fully exploited.

In a later experiment, the same abstract model of the SAGE IND Director's job was used to demonstrate that a taped lecture with logic flow diagrams on slides which were projected directly onto the control panel of the console could serve as a performance aid or teaching program (9). When the same logic diagrams were used in an instruction manual to supplement written text, training time was longer than with the tape/slides program.

A series of experiments were conducted using a querying/reasoning task to evaluate alternative training programs and performance aids. It was found that both practice and training modified performance. When routine bookkeeping of logical deductions was automatically provided to the naive operator, performance was as good or better than after any of a variety of training methods and moderate practice (7). It was also determined that a logic flow diagram of the task could serve as an efficient

and sufficient means of task instruction (9, 10).

A conceptual approach to ordering the content of programed instruction according to the "discovery" method was evaluated using a special multi-control console and display. The discovery principle was used to guide the trainee through a phylogenic evolution of system capabilities (7). Trainees who learned using the discovery, or phylogenic, organized program required less time and performed better than did those who used a conventional training program (9).

B. Logic Flow Diagrams

Techniques for task analysis and development of graphical logic flow diagrams were derived (10). The potential value of these diagrams for use as training aids was demonstrated for several widely differing tasks (7, 9, 10).

C. Engineering Design Principles and Considerations

General techniques and considerations for reducing instructional requirements, and for utilizing portions of the operational equipment for automated instruction, have been induced from the experiments and from a review of the literature (8).

The systems capabilities required to provide the training functions used in the experiments vary widely. For example, at one extreme the tape/slides program could be presented from a single low-cost tape recorder and projector without connections of any sort to the operational equipment (8, 9). However, the same program would be more effective,

and more costly, if the taped messages and slides were selected by the computer based on an evaluation of each successive operator response. In the latter case, access to the computer program must be available, and additional inputs provided to the computer from the individual controls. With respect to the use of a discovery or phylogenically ordered program, the required system capabilities are much more severe (9). Means for explicitly showing the need for each control function, identifying the control device, and for demonstrating the function can be provided from a program external to the operational equipment which merely displays situations according to a planned sequence on command. Requirements for response evaluation have not yet been thoroughly investigated. The verbal responses used in the experiments could not be reliably evaluated by present state-of-the-art equipment.

The economics of providing self-instructional features are highly dependent on the number of operators who will require training during the effective life of the equipment. For conventional training programs, the direct costs consist of: instructor's salaries, instruction materials (manuals, mock-ups, simulators), facilities (classrooms, fixtures, light, heat, etc.), cost of time spent in training, and costs of updating the instructors and materials for future systems. With self-instructional systems, the costs are in equipment modification, program preparation, cost of time spent in training, and cost of modifying the equipment and program for future systems (assuming that stand-by systems components are used).

D. Equipment Constructed

In the course of this study, three items of equipment were constructed. The first, the console used for the abstract model of the SAGE IND Director's task, has been previously described in detail (7). The second, the phylogenic console for controlling Lissajous figures, has also been described in an earlier report (9). The third item, a device for demonstrating probabilistic information processing, was not used experimentally and is described in the Appendix to this report.

IV. CONCLUSIONS AND RECOMMENDATIONS

1. The graphical symbology developed in this study provided a concise and efficient language for teaching the task logic for several representative tasks. It can be used independently or with other material in instructional programs. It is recommended that graphical logic flow diagrams be tried as teaching aids in an actual Air Force training situation.

2. Design, layout, and labeling of consoles in a topological relation to the task logic flow diagrams will facilitate implementation of self-teaching functions.

3. Performance aids and teaching aids beneficially modified behavior during a querying-reasoning task. Provision of automated bookkeeping greatly reduced training requirements, while provision of a task description which explicitly showed the contingencies governing each successive decision produced the most rapid performance improvement.

4. A phylogenic presentation of control function ordered according to the discovery principle is an effective format for instruction. Because of the potential value of this concept and present implementation problems, it is recommended that further research be directed towards refinement and ease of exploitation.

5. Slide/tape instruction programs can be used to provide on-the-job training or serve as performance aids with operational equipment. Since this technique can be evaluated in the field without requiring equipment modification, it is recommended that such a program be developed and used to meet an existing training need. Layout of future consoles to facilitate use of this technique should be deferred until the field evaluation is completed.

6. Varying degrees of self-instructional capabilities can now be included in Air Force Information Systems. Design principles and techniques should be disseminated and human engineering requirements modified to reflect the necessity for giving specific consideration to inclusion of self-instructional capabilities.

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VI. APPENDIX

An Inexpensive Probabilistic Information Processor (PIP)

As more sophisticated military information systems evolve, the users will gain access to a variety of probabilistic data. These data will facilitate decision making if properly interpreted. The mathematics of probabilistic information processing according to Bayes rule are well known and computers have been programed for this purpose. For situations in which computers are not available, the mathematical solutions can be computed manually.

If future information systems and sensors are to be fully exploited, users at all levels should be familiar with the fundamentals of Bayes rule. Simple inexpensive devices for computing probability data are needed to serve as training aids, or as performance aids in situations where access to full-size computers is not available.

An inexpensive and simple device for computing probabilities according to Bayes rule is described in the following paragraphs. Cost of components is kept low by using potentiometers for multipliers and the human operator as a nulling device.

For computing the successive probabilities of alternative hypotheses, given successive items of data, Bayes rule takes the form:

$$p\ (H_i \mid D_j) = \frac{p\ (D_j \mid H_i)\ p\ (H_i)}{\sum_i p\ (D_j \mid H_i)\ p\ (H_i)}$$

where: H_i is the inclusive set of all mutually exclusive "hypotheses" (causes).

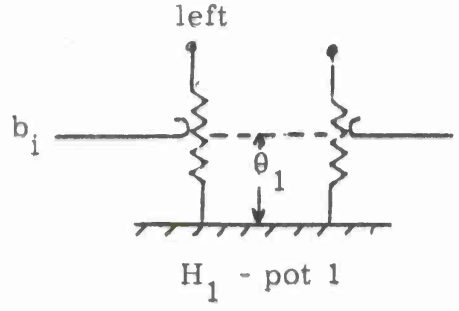
D_j is the set of data, observations, or "effects", where any of the D_j can be the effect of several H_i.

p is the probability.

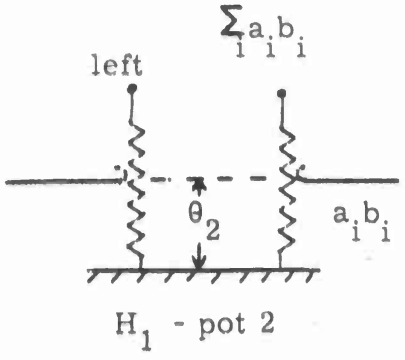
Given all present and past evidence, this equation is of the form:

Probability of a specific hypothesis $i = \frac{a_i \cdot b_i}{\sum_i a_i \cdot b_i}$, the solution of which serves as the a priori probability for the next step (i.e., the new $p(H_i)$).

Two potentiometers, each with two gangs, are arranged such that the voltage out of one gang of potentiometer 1 is $p(H_i) = b_i$ (there are as many sets of potentiometers as there are H_i). The output of the first gang, b_i, is then multiplied by a_i with a second potentiometer (this is a manual setting of $p(D_j \mid H_i)$ using a calibrated dial). All of the $a_i b_i$ are then added in an analog adder (requires one operational amplifier). Thus, both the numerator and denominator of the function $p(H_i \mid D_j)$ have been computed. The $\sum_i a_i b_i$ is then applied to ganged potentiometer number 2, and the wiper adjusted manually until its voltage (in terms of some current null instrument or ammeter) equals $a_i b_i$. When this adjustment is made, the other gang of this potentiometer shows a voltage $\frac{a_i \cdot b_i}{\sum_i a_i b_i}$ on its wiper by simple proportions.

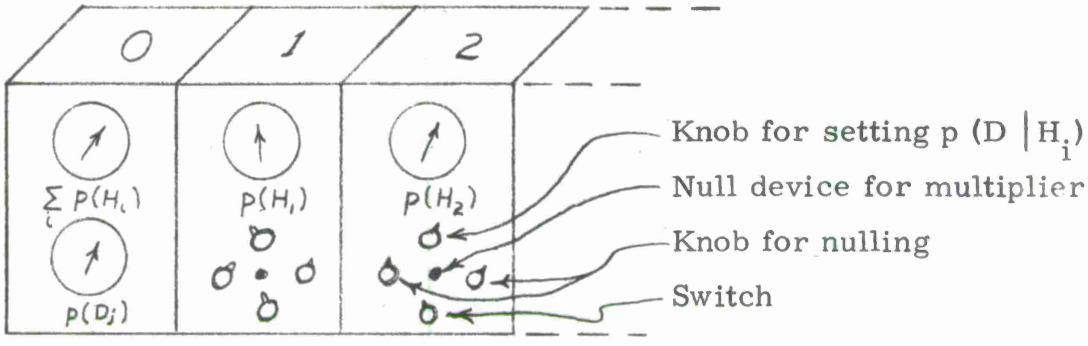


H_1 - pot 1



H_1 - pot 2

The equipment can be packaged in an arrangement such as shown below.



The box marked "0" on top would contain two analog adders, one to sum up the p (H_i) at each step to confirm to the operator that the sum was equal to unity, and the other to sum over-all p ($D_j \mid H_i$) p (H_i). Boxes marked 1, 2, ---would be identical. Each would display the present probability of any H_i, based on all previously processed D_j. The top row of the diamond of knobs is used by the subject to indicate his estimate of p ($H_i \mid D_j$). The other three knobs are for a perfunctory operation which the operator performs after he has gone down the line and set all of the p ($H_i \mid D_j$) knobs for that round.

Operation proceeds as follows:

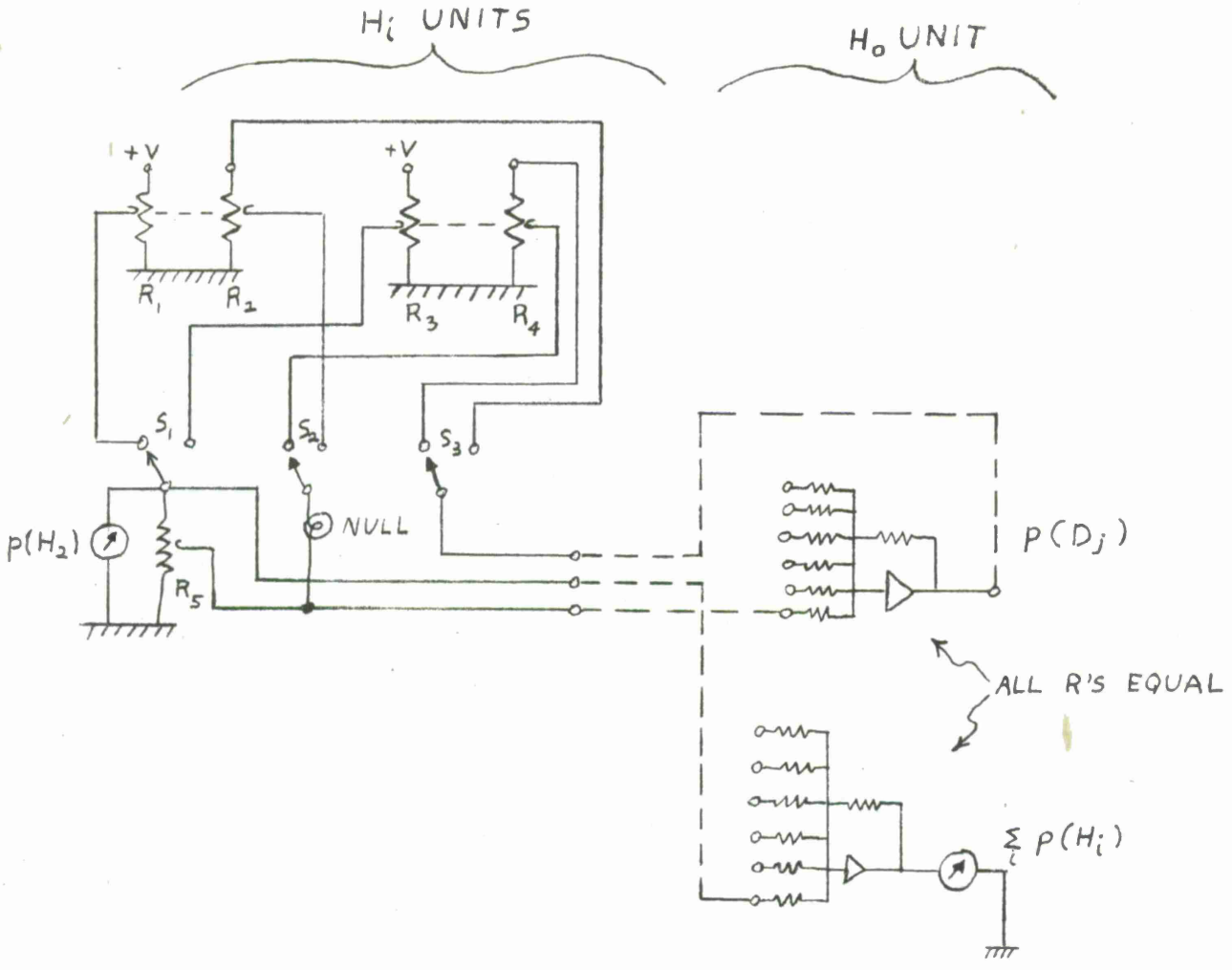
1. Set <u>a priori</u> p (H_i).

2. Adjust potentiometers for p ($D_j \mid H_i$) on each box.

3. Connect the output of the adder to pot 2 and adjust the wiper to null the product of steps 1 and 2 (do this for each H_i box down the line).

4. Switch over to the right-hand side of pot 1 and the left-hand side of pot 2 and repeat the cycle of operations with new data inputs (the voltage on the left gang of pot 2 is the new b_i, and the multipliers, analog adders, and null instruments are now connected between this gang and the right gang of pot 1).

A circuit diagram for a single H_i unit and H_0 box is shown below.



R_1 and R_2 ganged and low impedance.

R_3 and R_4 ganged and low impedance.

R_5 (for setting $p(D_j \mid H_i)$ is medium impedance.

All R's in the adders are equal and of high impedance.

Switches S_1, S_2, and S_3 are ganged.

A breadboard model of a two hypothesis PIP was constructed for demonstration purposes. It was found that inaccuracies can arise when

inexpensive linear pots must be used at 0-5% or 95-100% of their rotation ranges. However, in the middle ranges, the system approached slide rule accuracy. For other than demonstration or teaching purposes, ganged precision potentiometers would be required. The ratios of R_5 to R_1 and the adder R's to R_5 should be in the order of 50 to 1, and the meter resistance at least as large as the adder R's to achieve a moderate degree of precision.

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13. ABSTRACT

This report describes the results and conclusions of a study which was directed at the development of principles for the design of automated instructional subsystems for Information Systems. A series of four Technical Documentary Reports have been issued which describe in detail the activities and results of each aspect of the study. This report brings together and summarizes the results reported in the individual documents, and includes additional items which did not warrant separate documentation.

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